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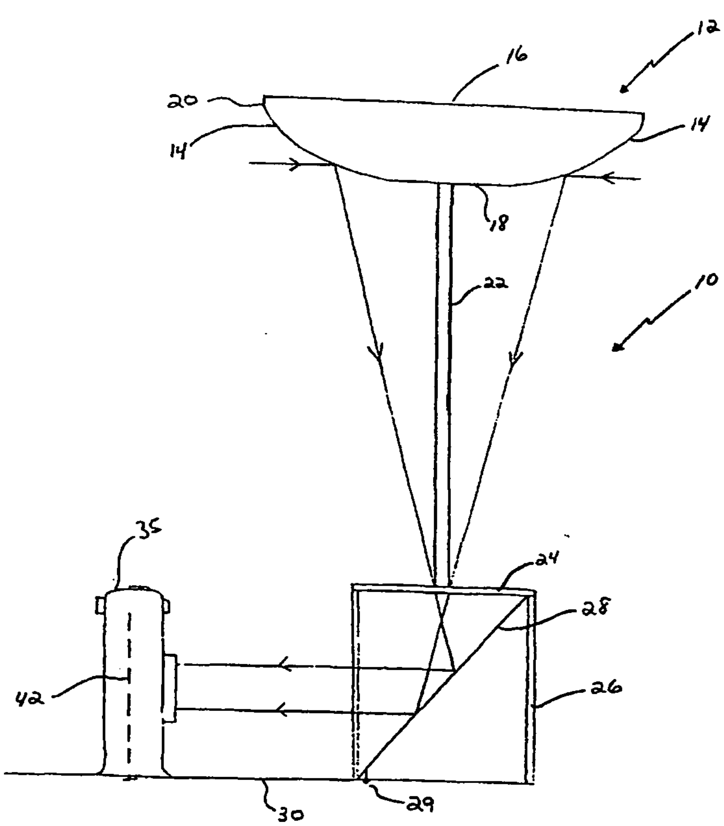

(57) **Abstract:** A panoramic imaging apparatus and method for capturing a 360 degree outward looking panoramic image of a scene using a single, stationary camera, comprises a mirror in the shape of an inverted dome, having an outward facing generally smooth convexly shaped peripheral surface for reflecting light emanating from the 360 degree panoramic scene, a camera - which may preferably be a still or video camera having a digital sensor such as a charge coupled device (CCD) sensor or a complementary metal oxide semiconductor (CMOS) sensor, but which may also be a conventional film based camera - for recording the image projected by the convex dome-like mirror, and a mounting system for attaching the camera to the mirror. The apparatus may also include a suitably programmed computer for dewarping and processing the image for display using a virtual reality display program.

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PANORAMIC 360-DEGREE IMAGING APPARATUS HAVING A CONVEX REFLECTOR DEFINED BY A CUBIC EQUATION, AND METHOD USING THE SAME

The present invention relates to a panoramic imaging apparatus and more particularly to an apparatus and method for capturing a 360 degree panoramic image of a scene using a single, stationary camera, for use in a virtual reality display system or to produce panoramic photographs.

BACKGROUND OF THE INVENTION

Virtual reality (VR) is becoming more and more popular and is a much desired new media entertainment and display concept. From video games that attempt to re-create the sense of live three-dimensional action, to Hollywood movies, to Web site displays that seek to put the viewer into the scene, virtual reality is in demand. People have a desire to experience the world from a realistic perspective that makes them feel like they are right in the action, and not just observing a flat two-dimensional picture from a single fixed vantage point.

In approximately 1995, Apple™ Computer released a computer program called Quicktime™ VR that allowed the navigation of a panoramic photograph on a computer screen by moving the computer mouse. One of the advantages of this general approach is that it is photo-realistic, while at the same time having very small file sizes that are easy to handle and are well suited for transfer from one computer to another. The navigation capabilities provide one with the sense of moving around in a three-dimensional space, as if one was actually present in the scene. Since that time, many other companies have released similar virtual reality display systems that can be used to view and navigate a panoramic photograph. These programs are now widely available and many of them are available free of charge.

Virtual reality display systems such as Quicktime™ VR require systems for quickly and inexpensively capturing high quality, 360 degree, panoramic images.

One of the difficulties in capturing the required panoramic image is that most currently existing photographic systems operate with a limited field of view and are unable to capture an entire 360 degree panoramic view of a scene. A standard

camera lens is only able to look outward at considerably less than 180 degrees. Even with so-called "fish-eye" lenses, the field of view is at most 180 degrees. Such systems are therefore unable to capture, in a single shot, a 360 degree view of a scene required for virtual reality viewing.

Over the past century, panoramic photography has used a wide variety of image capture techniques. All of these methods suffer from the disadvantages of being slow, inefficient and costly. The traditional approach to the problem is to take a number of pictures of a scene in a 360 degree panorama and carefully stitch them together. At one time, these separate images were merely mounted side-by-side on a cardboard backing, but now they can be scanned, converted to computer readable formats and combined using "stitching" programs. The resulting panoramic image is then converted to a format that can be displayed as a navigable virtual reality scene using a display program such as Quicktime™ VR. Of course, taking multiple photographs is costly and time consuming, and the scanning and stitching process tends to introduce artifacts into the final image. Furthermore, when separate images are stitched together, they tend to be uneven, requiring substantial cropping of the top and bottom of the scene.

Other panoramic image capturing techniques known in the art include: swing lens cameras that take images by swinging the lens during the exposure; rotational panoramic cameras that revolve on a tripod while the film moves in the opposite direction; and strip-scan panoramas, like those used to capture horses at a finish line, that expose the image of a moving object onto a piece of film moving at the same speed. All of these techniques are generally unacceptable for producing images for use in current virtual reality displays.

Some recent attempts have been made to address this problem by using only two photographs of the same scene taken in exactly opposite directions with a single fish-eye lens. However, the two photographs must still be carefully aligned and stitched together to produce the required 360 degree panoramic view. Again, the stitching process is slow and introduces artifacts into the final image. Moreover, any changes in lighting or object positioning within the scene between the two shots will cause disruption of the final image. A further disadvantage of using a fish-eye lens is

that it can introduce considerable radial distortion. That is, horizontal lines of an object near the top of a scene appear as curved rather than straight lines.

Another solution has been described in Canadian Patent Application No. 2,174,157 (Nalwa) which describes a four-sided, pyramid shaped reflective element to reflect images from four different directions to four different cameras having a common optical centre. The resulting images must also be stitched together electronically to form a continuous 360 degree view. One of the problems with this solution is that it requires multiple cameras which must be carefully aligned to ensure that each has the same optical centre. A further disadvantage is that the angle of the flat mirrors must be carefully aligned and maintained.

It is clear from the above that the techniques, skills and costs associated with obtaining 360 degree panoramic images suitable for virtual reality display applications could be significantly improved with the availability of innovative panoramic imaging devices and methods.

BRIEF SUMMARY OF THE INVENTION

The object of the present invention is to overcome the above shortcomings by providing a new and improved apparatus and method for rapidly obtaining high quality, inexpensive 360 degree panoramic images of a scene, using a single image obtained from a single stationary camera.

A further object of the present invention is to provide an apparatus and method of obtaining 360 degree panoramic images of a scene which, when converted to a format for display using virtual reality display software, are small in size and easy to manipulate.

Another object of the present invention is to provide a light weight, portable imaging apparatus for capturing 360 degree panoramic images of a scene.

Briefly, these objectives are achieved by the present invention, which provides a mirror in the shape of an inverted dome, having an outward facing generally smooth convexly shaped peripheral surface to reflect light emanating from

a 360 degree panoramic scene to be recorded by a suitable camera, which may preferably be a still or video camera having a digital sensor such as a charge coupled device (CCD) sensor or a complementary metal oxide semiconductor (CMOS) sensor, but which may also be a conventional film based camera. In a preferred embodiment, the inverted, dome-like convex mirror is mounted on a mast secured at one end through the central axis of the mirror and at the other end to the centre of a flat glass plate located on a horizontal plane perpendicular to the mast. The flat glass plate is mounted in a suitable structure above a flat mirror placed at a 45 degree angle to the flat glass plate so as to reflect light reflected downward from the mirror, 90 degrees towards a camera whose optical axis is perpendicular to the axis of the mast. In an alternative preferred embodiment, the inverted dome-like convex mirror is mounted directly above and coincident with the optical axis of the camera without requirement for a flat mirror to redirect the light by 90 degrees. In both cases, the inverted, dome-like convex mirror has a profile that projects a 360 degree view of the environment in which it is mounted onto the imaging plane of the camera.

The inverted, dome-like convex mirror projects a warped 360 degree image of the scene onto the image plane of the camera which records the image. Knowledge of the geometric definition of the mirror allows to transform a high quality 360 degree panoramic image of the original scene which can be displayed on a monitor or printed as a single flat image. The resulting de-warped image can also be formatted for display as a navigable three-dimensional image on a computer monitor using any widely available virtual reality display program, such as Quicktime™ VR for example.

In accordance with the objectives of the present invention there is provided a panoramic imaging apparatus for viewing a scene comprising: an inverted dome-like mirror having an outward facing convexly shaped peripheral surface, for reflecting a 360 degree panoramic view of the scene toward a single viewing location.

In a broad aspect, then, the present invention relates to a panoramic imaging apparatus for capturing panoramic images, comprising: a dome-like convex mirror, said convex mirror reflecting light from 360 degrees around said mirror; an image capture mechanism, said mechanism capturing said light reflected from said convex mirror; wherein said convex mirror is shaped as to be defined by a cubic equation.

In accordance with the further objectives of the present invention there is provided a method of recording a 360 degree panoramic image of a scene comprising the steps of: locating an inverted dome-like mirror having an outward facing convexly shaped peripheral surface within the scene so that said mirror reflects a 360 degree panoramic view of the scene; and sensing and recording said reflected panoramic view.

In another broad aspect, the present invention relates to a method of presenting panoramic images, said method comprising the steps of: recording a representation of a panorama; storing said representation as a digitized representation; geometrically transforming said digitized representation of said panorama; and displaying a resulting projection of said panorama.

The present invention advantageously provides for the rapid acquisition of high quality, professional grade 360 degree panoramic images at a much lower cost than professional grade optics. Yet another advantage is that the dome-like mirror and supporting apparatus can be made of plastic, further reducing costs and increasing portability. It is a unique single-surface mirror with a chrome-like bonded surface. A further advantage is that the present invention requires only a single camera and a single photograph to reproduce a 360 degree panoramic view of a scene. There is no requirement for multiple cameras or stitching together of multiple photographs. Another advantage is that the file sizes of the de-warped images produced by the present invention are much smaller than those typical of video. Therefore, when being viewed as a navigable three-dimensional image in a virtual reality display program such as Quicktime™, the images transfer much quicker and activate much faster.

Further objects and advantages of the present invention will be apparent from the following description, wherein preferred embodiments of the invention are clearly shown.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be further understood from the following description with reference to the drawings in which:

Figure 1 is a perspective view of a preferred embodiment of the present invention.

Figure 2 is a cross-sectional view of a preferred embodiment of the present invention showing an attached camera used for recording images.

Figure 3 is a plan view of a typical warped image of the simulated room shown in Figure 6 and projected on the image plane of a camera by the present invention.

Figure 4 is a cross-sectional view of the inverted dome-like convex mirror of the present invention.

Figure 5 is a graph showing the cross sectional surface curvature of a typical inverted dome-like convex mirror of the present invention.

Figure 6 is perspective view of a simulation showing a convex dome-like mirror of the present invention suspended in a simulated room.

Figure 7 is a schematic side plan view of an alternative embodiment of the present invention in which the dome-like mirror is attached directly to the camera.

Figure 8 is a schematic side plan view of an embodiment of the present invention which includes two convex dome-like mirrors used to image a substantially spherical view.

Figure 9 is a cross-sectional view of a further preferred embodiment of the present invention showing an alternative arrangement of the present invention collapsed for shipping purposes.

Figure 10 is a flow chart showing an embodiment of a method of the present invention for acquiring and processing panoramic images.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

Referring to Figure 1, a preferred arrangement of the present imaging apparatus **10** is shown which comprises an inverted dome-like mirror **12** having an outward facing convexly shaped peripheral surface **14**. Dome-like mirror **12**, as also shown in isolated cross-section in Figure 4, has a horizontal flat base **16**, a horizontal flat top **18** and a vertical edge **20**. Vertical edge **20** is added to the preferred arrangement shown for the purpose of increasing the strength of the mirror, but is not a required feature of the present invention. Dome-like mirror **12** uses complex geometry rather than a polar rectangular transformation. The convex shape of the

invention has been specifically designed to produce poor quality images, in which straight lines look bent and objects appear distorted, when a transformation from polar coordinates to rectangular coordinates is used. This is the most common geometric fit used with either concave or convex mirrors. The mirror of the present invention goes beyond this in defining a shape that is more sophisticated therefore making it more difficult to find a fit that matches the shape for dewarping purposes.

The shape of the mirror **12** is defined by a cubic equation. It is also key to compensate in the shape definition for the smaller central than outer circumference on the mirror **12**. Since there is more surface area on the outer rim of the mirror **12**, there tends to be more pixels there and better resulting resolution in that area of the reflection. In order to compensate, the inner mirror slope of the present invention accounts for this situation in that bands on the inner circumference are approximately 2.3 times taller than around the outer rim. Using geometric projections based on a cubic function also allows for a very wide vertical field of view with versions at 45 degrees viewing up and 45 down, for a total vertical field of view of 90 degrees, and 52 degrees up and down, for a total of 104 degrees, and 60 degrees up and down for a wide angle vertical view of 120 degrees up and down. Said mirror **12** also allows for symmetry, with the same number of degrees above and below the horizon. It is further designed to balance the number of pixels or light rays coming in from above and below the horizon. The shape is also designed to minimize the blindspot in the centre of the mirror.

Dome-like mirror **12** is supported in an inverted position by mast **22** attached at one end through the centre of mirror top **18** and at the other end to a flat transparent plate **24**, preferably made of either glass or plastic, positioned on a horizontal plane perpendicular to mast **22**. Flat transparent plate **24** is supported in a suitable structure such as a glass or plastic support cube **26** or tube, however, it will be appreciated by one skilled in the art that any suitable supporting structure would function equally well in the present arrangement for supporting dome-like mirror **12**. In the illustrated embodiment of the invention, a flat mirror **28** is located in the structure below flat transparent plate **24** and is positioned at an angle of 45 degrees to flat transparent plate **24**. To assist in the alignment of the image reflected from dome-like mirror **12**, the angle of flat mirror **28** in relation to flat transparent plate **24** can be made adjustable using an adjustment screw **29** (see Figure 2) located at the

base of flat mirror **28**. Imaging apparatus **10** includes a track **30** attached to the base of support cube **26** and extending at an angle of 90 degrees to mast **22**.

As shown in Figure 2, track **30** supports a camera **35** (the image capture mechanism) which is removably attached to track **30** and located so that its optical axis is perpendicular to mast **22** and most, if not all, the curved surface **14** of dome-like mirror **12** is within the field of view of the camera. Camera **35** can be any suitable imaging device such as a film based still camera, a movie camera, or a still camera or video camera having a digital image sensor such as charged coupled device (CCD) sensor or a complementary metal oxide semiconductor (CMOS) sensor. Camera **35** is movable along track **30**, allowing it to be located either closer to or farther away from flat mirror **28**, permitting adjustment of the image size and location on an image plane **42**. A zoom in camera would serve the same function. Further, it should be noted that the software used in combination with the present invention allows for the resulting image to be flipped depending on which device might be used.

Figure 3 shows a warped circular image **40** of the outward environment as shown in Figure 6 and projected onto image plane **42** of camera **35** by the arrangement of the present invention shown in Figures 1 and 2. The warped circular image **40** represents 360 degrees in azimuth of the viewed environment and from approximately -90 degrees (that is vertically downwards in the arrangement shown in Figure 2) to greater than 0 degrees (horizontal) in elevation. In practice, the lowest elevation is determined by the size of flat top **18** of dome-like mirror **12** which blocks the downward view of the mirror at the lowest elevations. The highest elevation is determined by the curvature of the convex surface of the dome-like mirror **12** or its cross-sectional profile as shown in Figure 5, and generally extends equally far above the horizon so that objects above 0 degrees elevation, in the range of 45, 52 or 60 degrees elevation, are visible.

In the warped circular image **40** generated by the dome-like mirror **12**, a given radial direction corresponds to a specific azimuth in the environment, and since the warped image produced by the dome-like mirror **12** is inverted, increasing radii correspond to increasing elevations. Thus, in the warped image **40** shown in Figure 3, the outer portion of the circle corresponds to the ceiling or top of the

environment shown in Figure 6, while the inner edges of the circle correspond to the bottom or floor.

The convex surface profile of dome-like mirror **12** may be any one of a large number of practical profiles, but in the case of the preferred arrangement of the present invention described herein, the convex profile of dome-like mirror **12** is preferably chosen to map equal changes in elevation in the scene to equal changes in radius in the warped image. This ensures that both the top and bottom of the scene receive an equal number of image pixels, thus preventing stretching or distortion of image lines which is a common problem for imaging systems using convex mirrors.

As shown in Figures 1, 2 and 4, inverted dome-like mirror **12** has a flat base **16**, and a small flat top **18**, which is created by slicing the top off. In one preferred embodiment of the present invention, base **16** has a radius of approximately 1.6 inches and top **18** has a radius of approximately one-quarter inch.

The profile of dome-like mirror **12** was chosen by conducting extensive simulations based on geometric projections. The convex curvature of surface **14** was varied and different sections were selected, until the ideal combination was obtained which, when inverted, projected a symmetric view above and below the horizon with more surface area or central concentric circles, high vertical field of view, while using a cubic geometric function, resulting in a distorted image if a polar rectangular transformation was used. One preferred curvature for the surface **14** of dome-like mirror **12** is shown in Figure 5.

The various dimensions of the present invention as shown in Figure 2, will vary depending on the type of camera **35** used and the exact positioning and curvature of the dome-like mirror **12**. In one typical arrangement, the applicant has attached a Nikon™ digital camera to track **30**. In this preferred arrangement, the Nikon™ camera is located three-quarters of an inch from the base of mirror **28** which is set at a 45 degree angle within support structure **26** which measures four inches long, two and one-half inches wide and two and four-tenths inches high. The base **16** of dome-like mirror **12** is four inches in diameter and the top **18** is one and

one-half inches in diameter, and the dome-like mirror **12** is supported on mast **22** approximately five and one-quarter inches above the surface of transparent plate **24**.

It is important to select the diameter of top **18** so as to prevent imaging of objects directly below the dome-like mirror, such as camera **35** or support **26**. This permits placement of the camera much closer to the dome-like mirror **12**. Placement of the camera closer to the dome-like mirror **12** helps to eliminate vibration and improves the portability of the system.

As shown in Figures 1 and 2, it is important that during operation mast **22** not extend through the flat transparent plate **24** by any significant amount. Any extension of mast **22** into the optical field of view of camera **35** will result in an image of mast **22** appearing on the image plane of the camera. If mast **22** is merely imbedded in transparent plate **24**, or securely screwed in, the entire mast is obscured by the blind spot created by top **18** of dome-like mirror **12**, which appears as a small dark circle in the centre of the circular warped image **40**. On the other hand, the extension tube moves the end of the mast away from the camera, to make the blindspot look smaller.

However, referring to Figure 9, in order to reduce the size of the arrangement of the present invention shown in Figures 1 and 2, during shipment or storage, mirror **28** can be provided with a central hole **50** located directly inline with mast **22**. Mast **22** can be constructed so as to be slidably secured within transparent plate **24** thereby permitting mast **22** to be lowered through hole **50** reducing the size of the present invention for shipping or storage. Hole **50** is obscured by the blind spot of the apparatus created by the size of top **18** and is thus not visible on the image plane **42**.

The positioning of flat mirror **28** at a 45 degree diagonal is a further important aspect of the preferred embodiment of the invention shown in Figures 1 and 2. A similar arrangement has been used in telescopes to reflect light gathered from a large primary mirror and direct it at an angle of 90 degrees to the optical axis of the primary mirror for focussing and viewing. The arrangement is referred to as a "Newtonian Reflector" and, as used in the present invention shown in Figures 1 and 2, permits camera **35** to be placed at a 90 degree angle to the optical axis of dome-

than upwards vertically toward the dome-like mirror. The arrangement also permits the use of almost any type of camera so long as it can be mounted on track **30** and does not limit the invention to cameras which can be mounted directly to the dome-like mirror **12**.

In an alternative embodiment of the present invention, as shown in Figure 7, camera **35** is mounted on mast **22** or more conveniently through an adapter tube to fit the camera directly in line with dome-like mirror **12** so that the optical axis of camera **35** coincides with the optical axis of dome-like mirror **12**. In this alternative arrangement, the 360 degree panoramic image of the environment reflected from the dome-like mirror **12** is projected directly onto the image plane **42** of camera **35**, thus eliminating the requirement for flat mirror **28**. One advantage of the arrangement shown in Figure 7 is that the entire apparatus can be made smaller and lighter and is thus more portable.

As mentioned above, and as shown by example in Figure 3, the circular image **40** produced on image plane **42** of camera **35** by the present invention is usually a warped version of the viewed environment in which the azimuth corresponds to the environmental azimuth and the radial distance corresponds to the elevation angle.

To interpret this warped image and to produce an image that is usable in a virtual reality viewer such as Quicktime™ VR, the warped image must be de-warped using a suitably programmed computer or microprocessor to transform pixels in the warped image to rectilinear coordinates.

In an alternative embodiment of the present invention, ridges or similar aberrations may be positioned, in ring-like fashion around the dome-like mirror **12**, in close proximity to flat top **18**. This will result in making unwarping more difficult and can be seen as an added security feature.

Finally, the resulting de-warped image can be printed or displayed as a panoramic photograph or further processed and formatted for display using any virtual reality viewer such as Quicktime™ VR. Alternatively, the electronic signal generated by a camera having a CCD or CMOS sensor at its imaging plane can be

de-warped directly in the camera or in a set top box, thus producing a de-warped image formatted for display on a monitor or in a virtual reality viewer. If the camera used is a video camera and the computer used has sufficient processing power and transmission bandwidth, it is within the concept of the present invention that successive images can be captured, processed and actively displayed to create a live, full-motion, three dimensional navigable display of the viewed environment.

In practice, the present invention is extremely simple to use. For many applications the most advantageous panoramic view of a scene is one taken from the perspective of a standing or seated person. Using either of the preferred embodiments of the present invention described and shown in Figures 1 and 2 or Figure 7, the operator, while standing or sitting, simply holds the invention at or slightly above eye level and activates camera **35** to record an image of the scene. Because of the small blind spot created by top **18** of dome-like mirror **12**, both the operator and the camera are not recorded in the resulting panoramic image. For more serious applications, the apparatus can be placed on a centrally located tripod and the camera activated remotely or by timer.

Referring to Figure 10, there is shown a flow chart illustrating a method for acquiring and processing panoramic images in accordance with an embodiment of the present invention. The steps include locating an inverted dome-like mirror in the environment to be viewed **110**, reflecting a 360 degree panoramic view of the environment from the dome-like mirror **115**, and sensing and recording the warped image reflected therefrom **120**. The method may further include de-warping the warped images by transforming pixels in the warped image to rectilinear coordinates **125**, displaying the de-warped image on a monitor or printing the image as a panoramic image **130**, and further processing and formatting of the de-warped image for display using a virtual reality viewer **135**, thus permitting three-dimensional navigation of the viewed environment.

It is contemplated that the steps of locating the mirror **110**, reflecting the scene **115** and sensing and recording the warped image **120** can be done remotely by a person using the preferred arrangements of the present invention discussed above. It is further contemplated that the warped image thereby recorded can be submitted to a central location where the further steps of de-warping the image **125**,

printing a panoramic photograph **130**, or processing and formatting the image for display using a virtual reality viewer **135** are performed. To that effect, it is contemplated that in a preferred embodiment of the invention, a central control program will include authentication software. To initiate the image capture process, a user must contact a central location to activate authentication software by obtaining an authorization number in exchange for payment of an image processing fee. This approach allows the applicant to make the invention available to remote users while at the same time maintaining the ability to collect user fees for image processing. Users purchase the image processing to create a virtual reality scene, not the entire software.

Alternatively, the user can be allowed to save an assembled demo image, including a watermark, before authentication software is engaged and the processing fee is paid. This will allow a user to preview the assembled image or show it to clients before incurring a processing fee. Once the central location is contacted and the processing fee paid, the watermark is removed.

In a further preferred embodiment, it is unnecessary for the user to make contact with the central location to obtain an authorization number each time a final assembled image is processed. In this embodiment of the invention, authentication software includes a use counter indicating an available number of uses. Each time a final assembled image is processed for export to a virtual reality viewer, the use counter subtracts one from the total available uses, until none remain. A user can obtain additional uses by purchasing a processing code number, which is used by authentication software to reset the use counter with a desired number of uses. The processing code number is a unique number which designates the number of processing units purchased and specifies the individual computer on which it can be used. The processing code number is obtained by contacting the central location, requesting the desired number of uses, and providing a unique computer identifier number generated by authentication software. The computer identifier number is generated by authentication software from a serial number or numbers read from devices connected to a computer, such as the computer's mother board or hard drive to ensure that the requested processing uses are made available to only one computer.

As shown in Figure 8, a field of view that is almost global in scope may be obtained by using two convex dome-like mirrors **12** mounted base-to-base, and sharing a common optical axis. The arrangement shown in Figure 8 utilizes two identical devices as shown in Figure 7, each having convex dome-like mirror **12**, a supporting mast **22** and a camera **32** mounted so that the optical axises of the cameras **35** are coincident with the optical axises of the dome-like mirrors **12**. One of the main advantages of this alternative arrangement is that the resulting images obtained from each mirror can be combined in the final de-warped image to produce a navigable three-dimensional image having 360 degrees of azimuth and a range in elevation from almost -90 degrees vertically downward to almost +90 degrees vertically upward. The field of view in the final three-dimensional navigable scene is thus greatly expanded over an arrangement using a single dome-like mirror **12**.

The imaging apparatus and method of the present invention has applications in a wide number of areas requiring panoramic photographs and interactive panoramic displays, of which the following is a brief, but not exhaustive, list:

virtual home tours in the real estate industry;

virtual field trips to remote locations for use by educators and in the tourist industry;

virtual store tours and displays for on-line retailers,

virtual displays of entertainment venues to provide virtual spectator views from particular seat locations; and

visualization of harsh industrial environments.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiments are therefore to be considered as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes that come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A panoramic imaging apparatus for capturing panoramic images comprising:

a dome-like convex mirror, said convex mirror reflecting light from 360 degrees around said mirror;

an image capture mechanism, said mechanism capturing said light reflected from said convex mirror;

wherein said convex mirror is shaped such as to be defined by a cubic equation.

2. A panoramic imaging apparatus as defined in claim 1 wherein said image capture mechanism is an electronic camera having a charge coupled device (CCD) sensor at its image plane and the output of said sensor is connected to signal processing means.

3. A panoramic imaging apparatus as defined in claim 2 wherein said signal processing means is programmed to produce a dewarped image.

4. A panoramic imaging apparatus as defined in claim 3 wherein said signal processing means are in a camera.

5. A panoramic imaging apparatus as defined in claim 3 wherein said signal processing means are in a set top box.

6. A panoramic imaging apparatus as defined in claim 2 wherein said image capture mechanism is a video camera or a still camera.

7. A panoramic imaging apparatus as defined in claim 1 wherein said convex mirror is shaped such as to compensate for a smaller central than outer circumference.

8. A panoramic imaging apparatus as defined in claim 7 wherein said convex mirror is shaped so that bands on an inner circumference are approximately 2.3 times taller than around the outer circumference.

9. A panoramic imaging apparatus as defined in claim 1 wherein said convex mirror is shaped to produce distorted images when a polar-rectangular transformation is used.

10. A panoramic imaging apparatus as defined in claim 9 wherein the convex mirror is comprised of a single surface.

11. A panoramic imaging apparatus as defined in claim 10 wherein the mirror is a first-surface mirror with a durable chrome-like bonded surface.

12. A panoramic imaging apparatus as claimed in claim 1 wherein ridges are located in ring-like fashion around said convex mirror.

13. A panoramic imaging apparatus as claimed in claim 1 wherein the images are symmetric above and below the horizon.

14. A panoramic imaging apparatus as claimed in claim 1 wherein a screw is mounted in a flat glass rod to the mirror.

15. A method of recording a 360 degree panoramic image of a scene comprising the steps of:

locating a dome-like mirror having an outward facing convexly shaped peripheral surface within the scene so that said mirror reflects a 360 degree panoramic view of the scene; and

sensing and recording said reflected panoramic view.

16. A method of presenting panoramic images, said method comprising the steps of:

recording a representation of a panorama;

storing said representation as a digitized representation;

geometrically transforming said digitized representation of said panorama; and

displaying a resulting projection of said panorama.

17. The method as claimed in claim 16 wherein said step of geometrically transforming the digitized representation is a cubic function.

18. The method as claimed in claim 17 wherein the transforming can be done in a computer, a camera or a set top box.

19. The method as claimed in claim 16 wherein the step of displaying a resulting projection comprises running a Quicktime™ VR program.

20. The method as claimed in claim 16, said method comprising the further step of:

centrally controlling the storing, transforming and displaying steps.

21. The method as claimed in claim 16 wherein a processing code number is allocated.

22. The method as claimed in claim 16 wherein a unique computer identifier number is generated by authentication software.

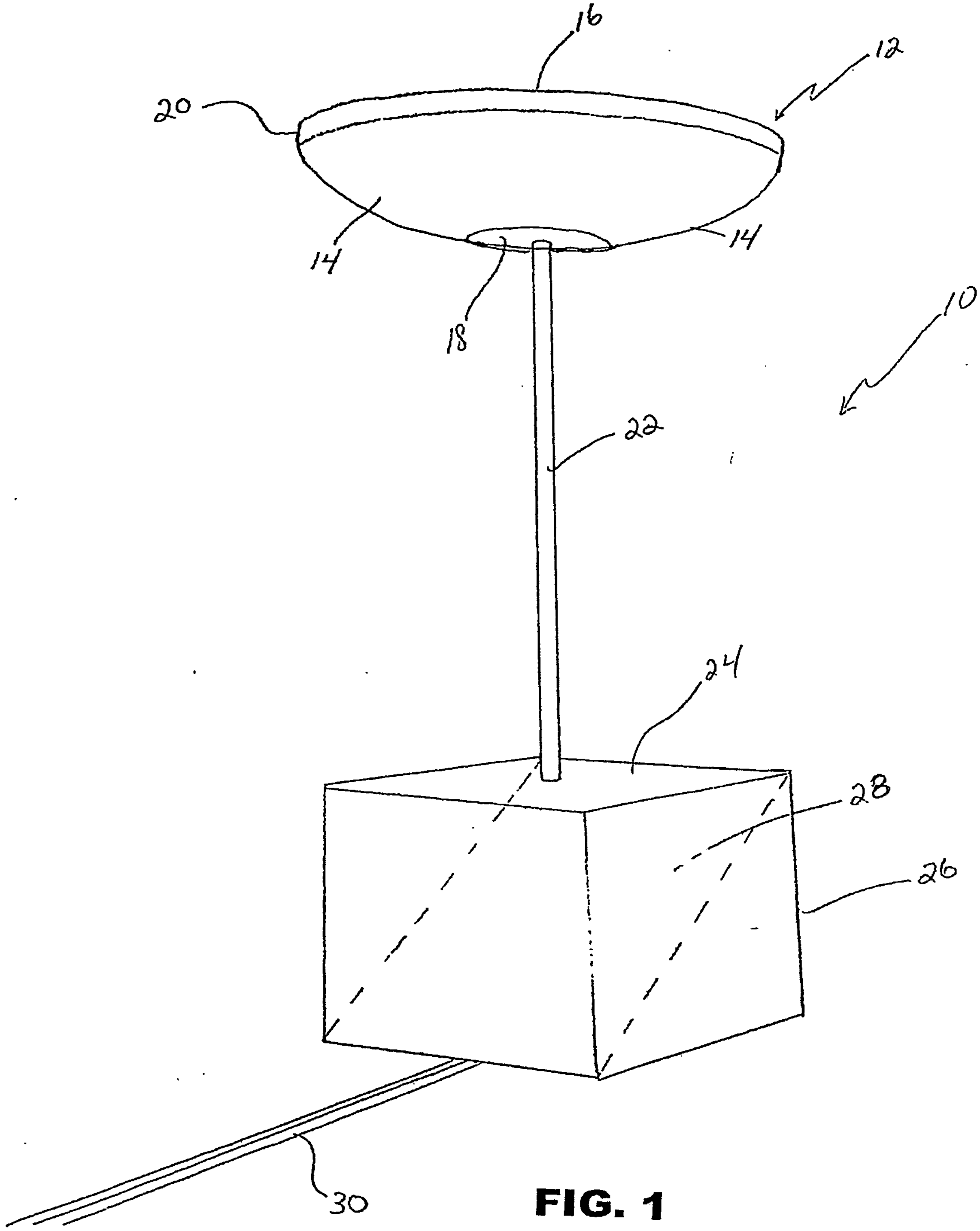

FIG. 1

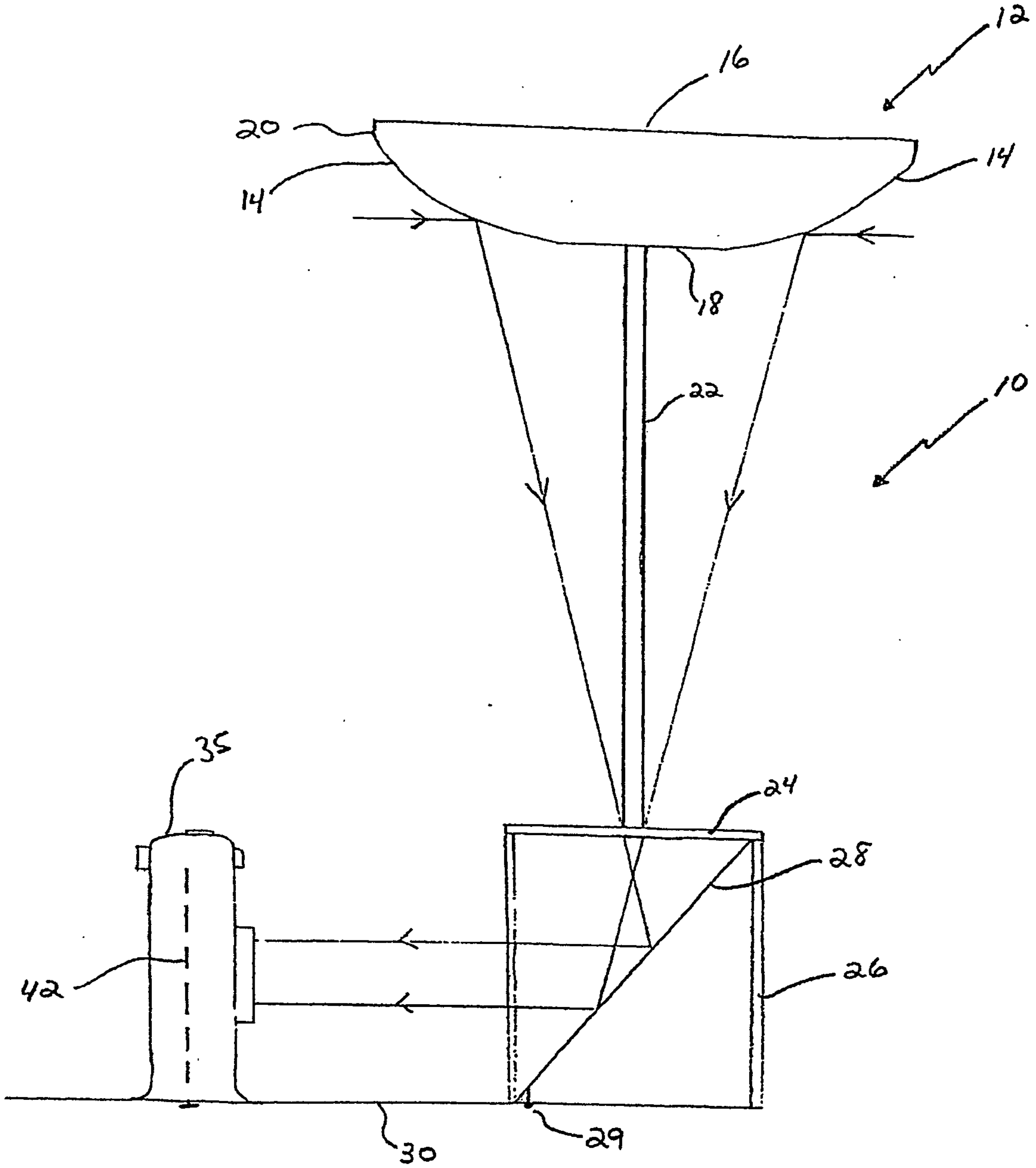

FIG. 2

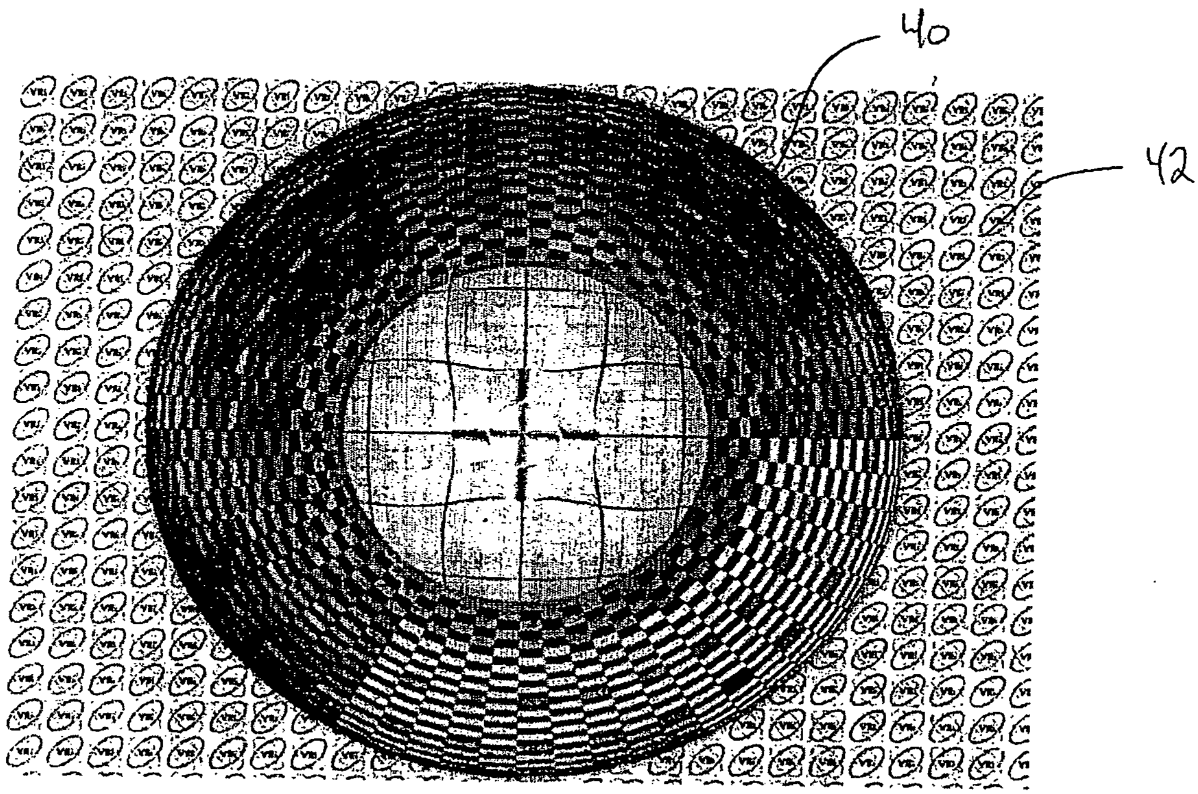

FIG. 3

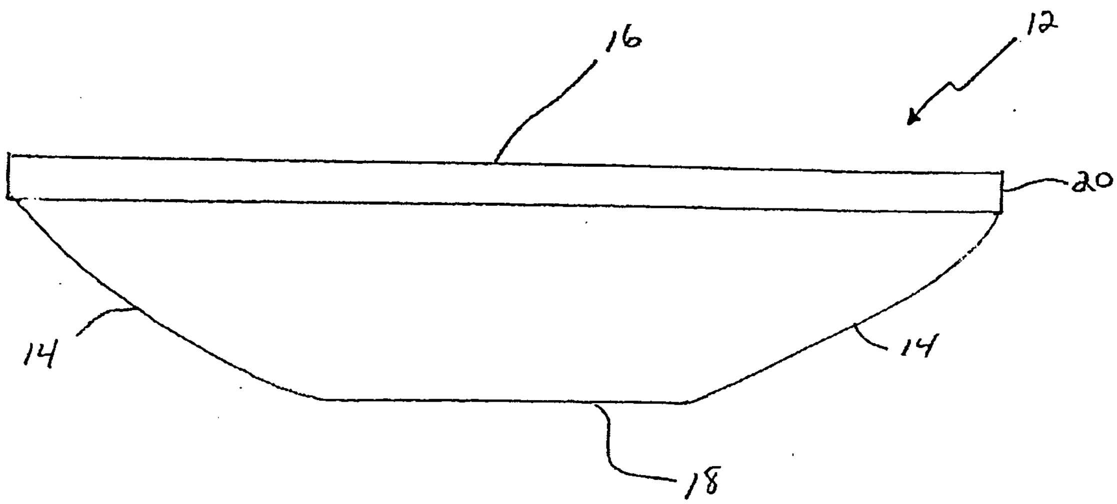

FIG. 4

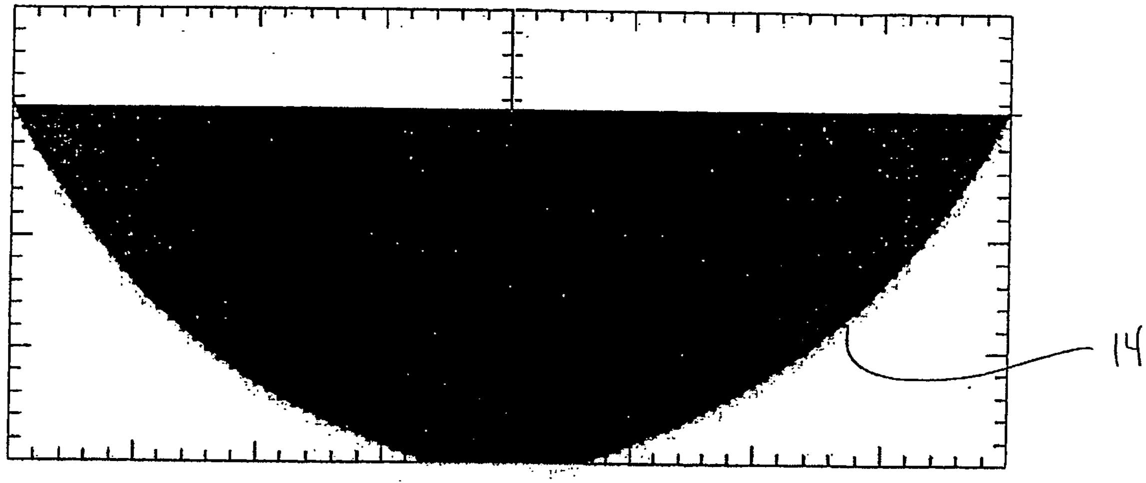

FIG. 5

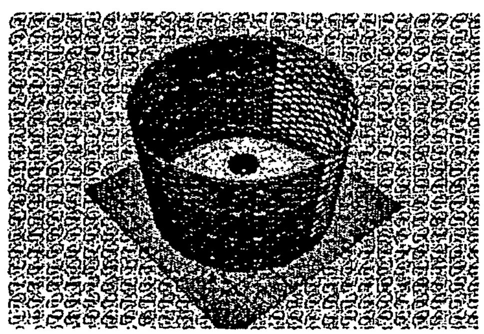

FIG. 6

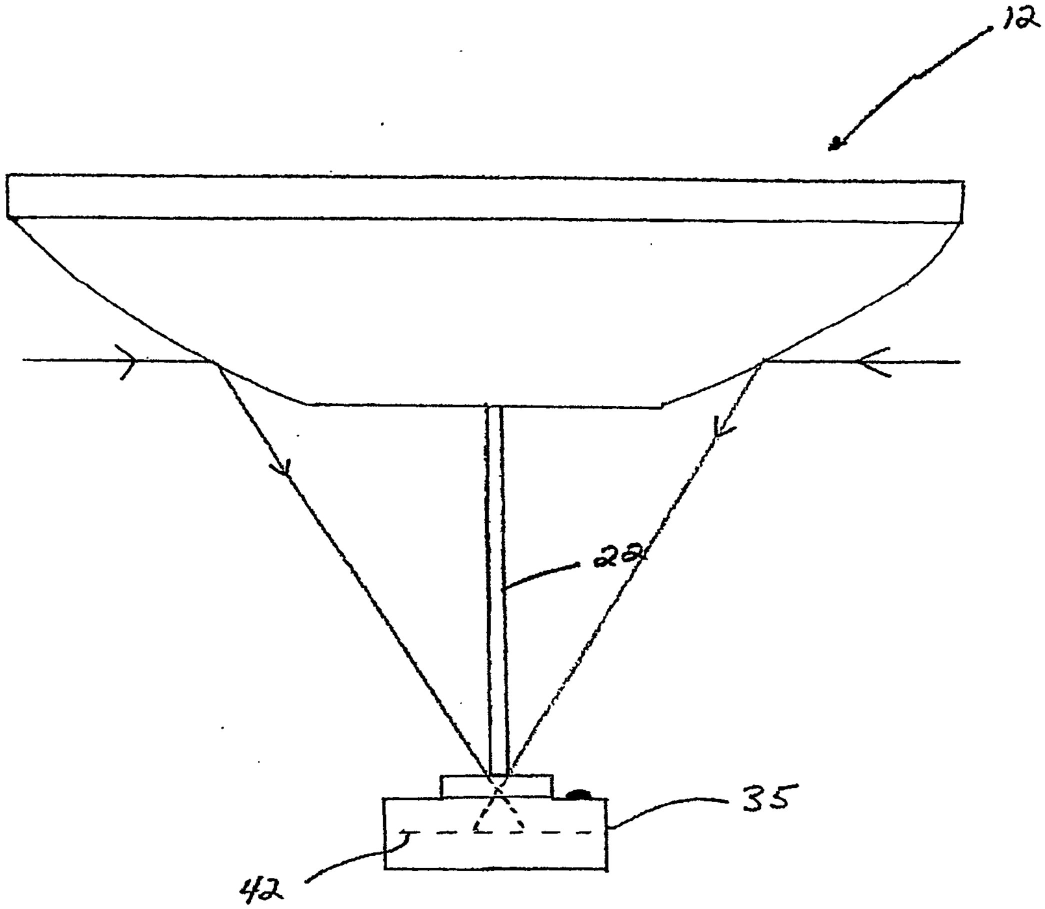

FIG. 7

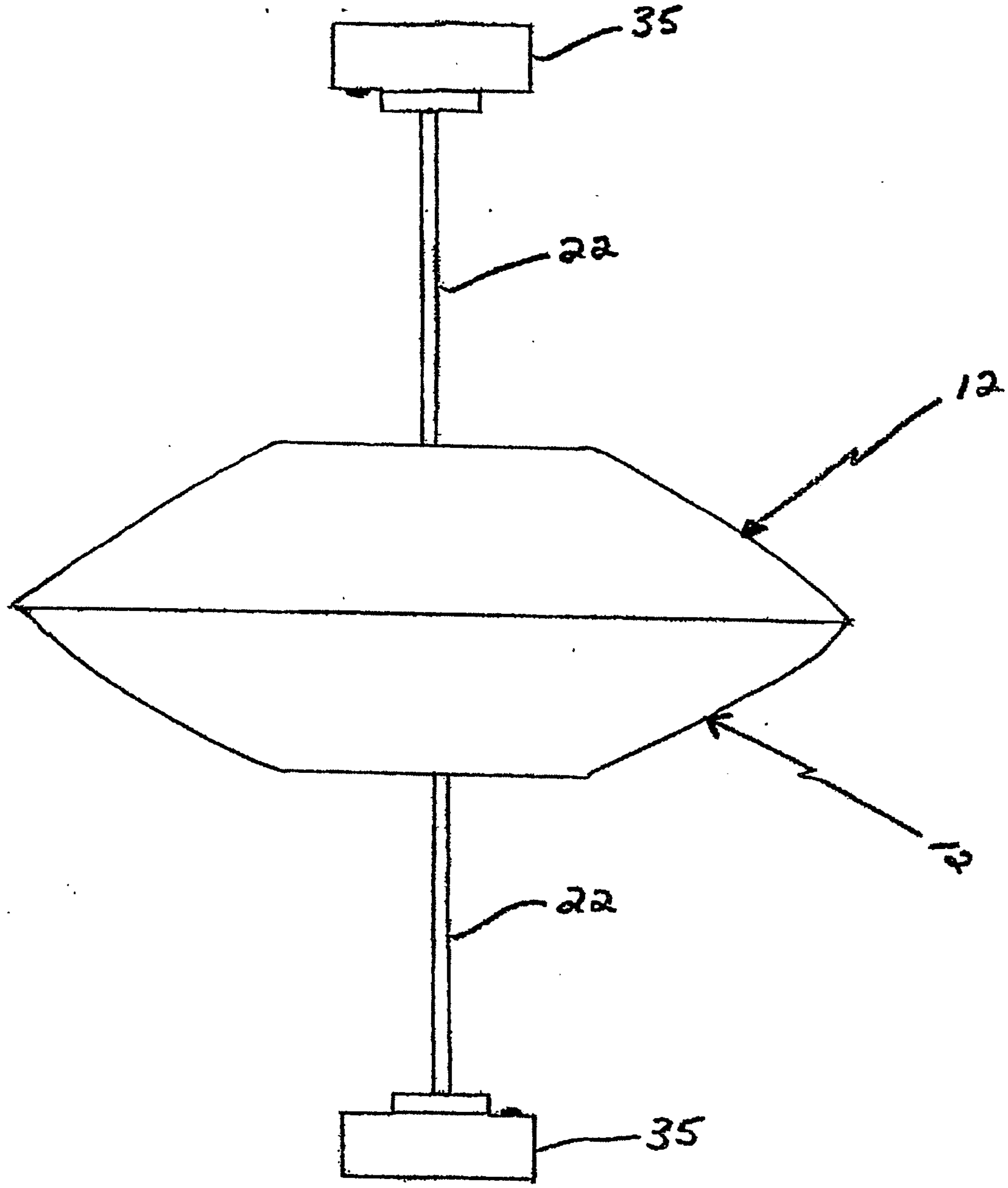

FIG. 8

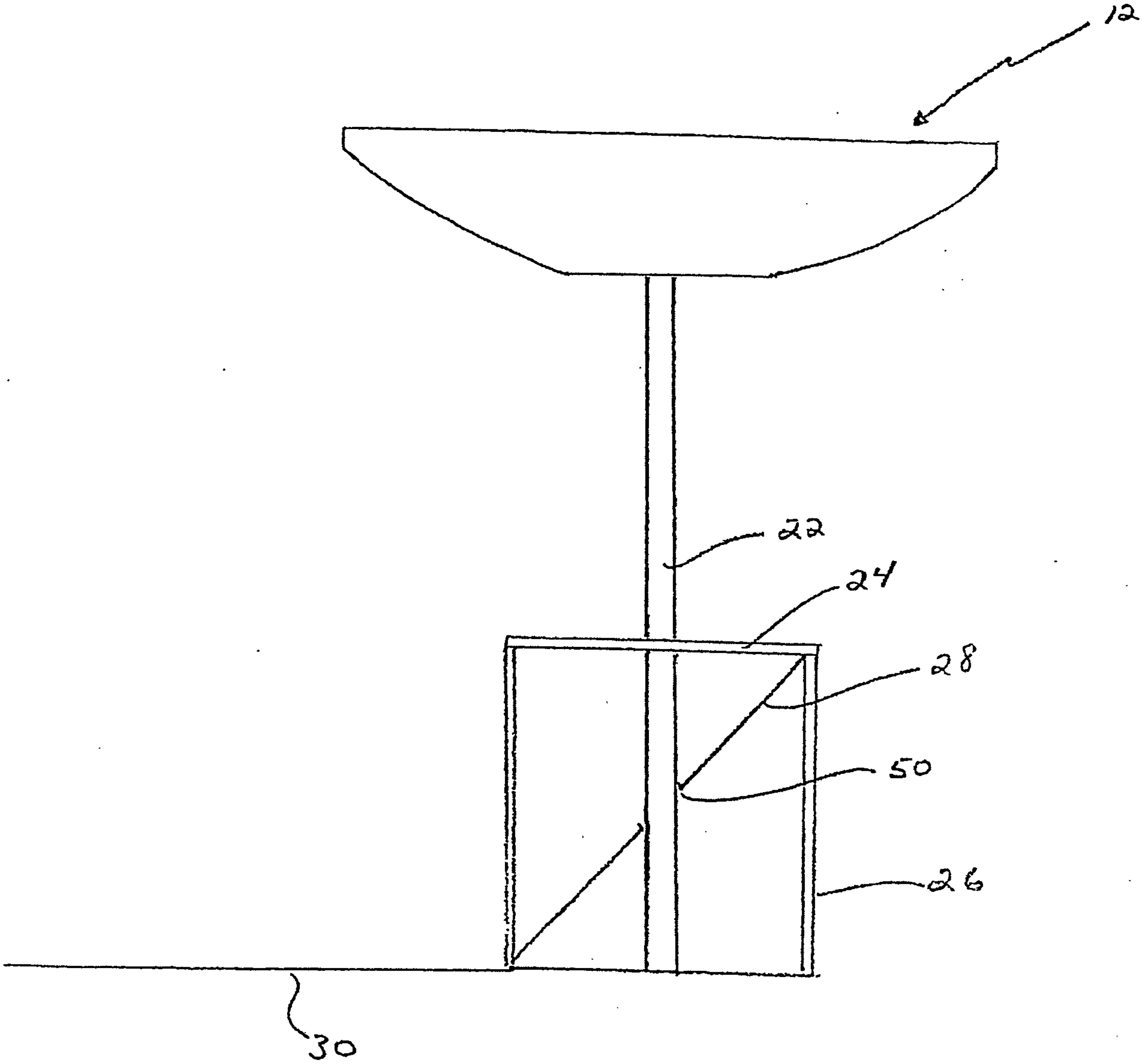

FIG. 9

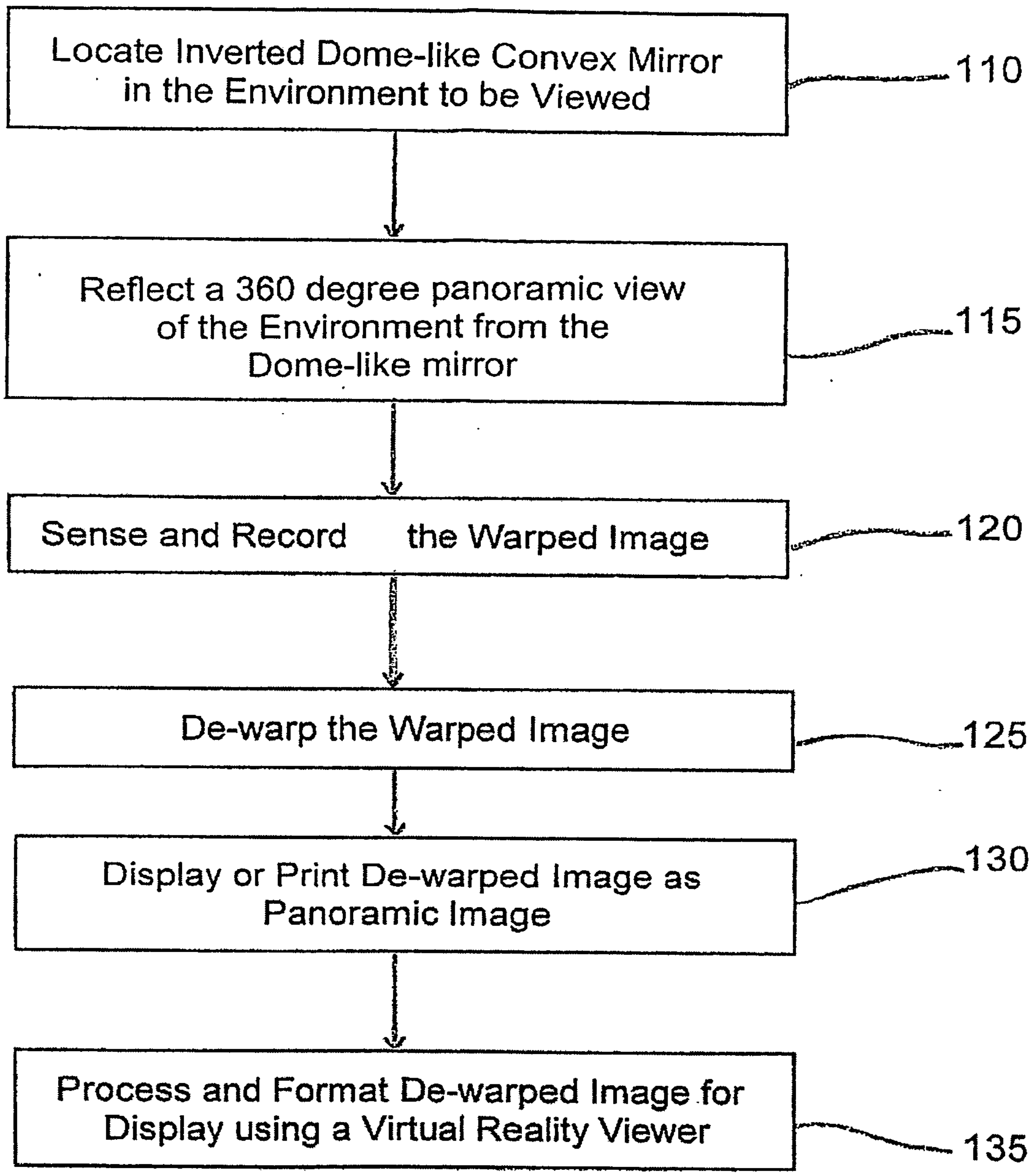
Locate Inverted Dome-like Convex Mirror in the Environment to be Viewed
110
Reflect a 360 degree panoramic view of the Environment from the Dome-like mirror
115
Sense and Record the Warped Image
120
De-warp the Warped Image
125
Display or Print De-warped Image as Panoramic Image
130
Process and Format De-warped Image for Display using a Virtual Reality Viewer
135

FIG. 10

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B13/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B G03B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 10, 17 November 2000 (2000-11-17) & JP 2000 206635 A (YISHENG SCIENCE &TECHNOLOGY CO LTD), 28 July 2000 (2000-07-28) abstract	15
A	US 4 566 763 A (GREGUSS PAL) 28 January 1986 (1986-01-28) abstract; claims 1,2,4; figure 4 column 2, line 17 - line 38	1-22
A	US 5 745 305 A (NALWA VISHVJIT SINGH) 28 April 1998 (1998-04-28) cited in the application the whole document	1-22

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 March 2003	18/03/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Michel, A

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